Far-Infrared Emission Line Diagnostics of Galaxies

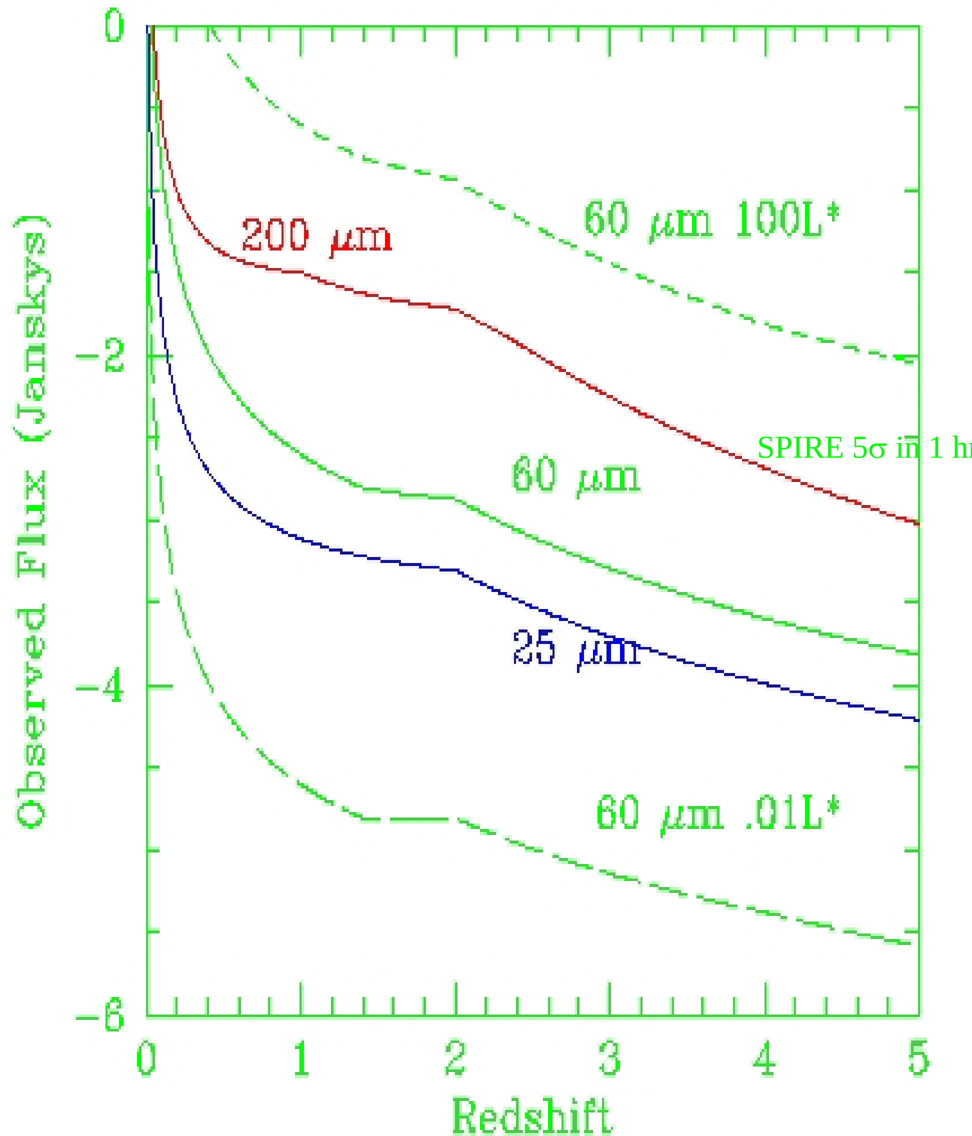
Matt Malkan (UCLA)   *Luigi Spinoglio (IFSI)*

SUMMARY

We used ISO-LWS to measure the three strong emission lines [OI]63μm, [OIII]88μm, and CII]158μm in a large sample of galaxies of various types. We show that a simple combination of the ratios of these lines provide an excellent diagnostic of the source of the excited and ionized gas. Even fairly rough measurements can separate quiescent disk galaxies from those harboring starbursts or Seyfert nuclei. These strong lines will thus be prime spectroscopic diagnostics for the dusty high-redshift galaxies which will be uncovered by Herschel, and at even higher redshifts by ALMA.

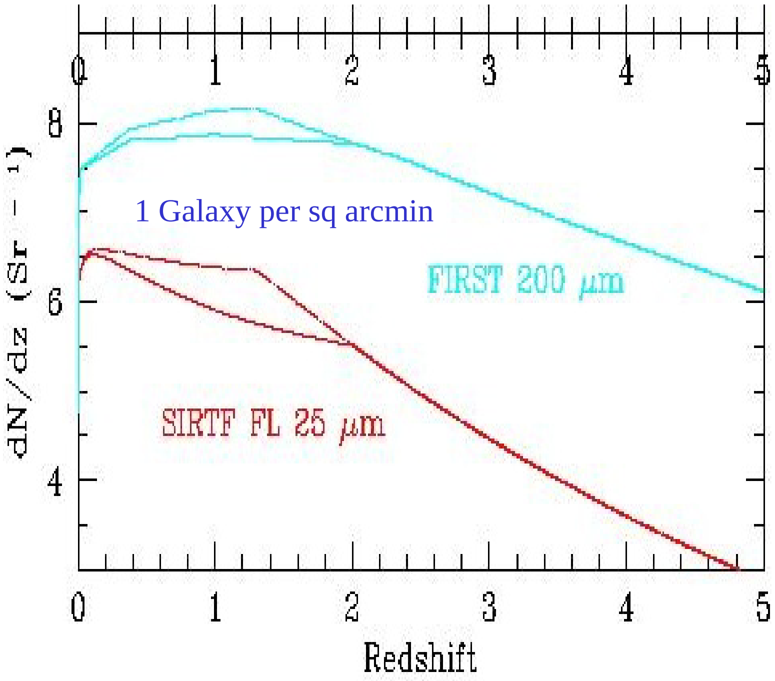
Scientific Motivation:
Studying Galaxy Evolution

Detecting the thermal dust ***CONTINUUM*** from normal L_* galaxies at the ***highest redshifts*** in the Far-IR will be easy with *Herschel* imaging: favorable K correction makes them brighter than 1 mJy out to z = 5



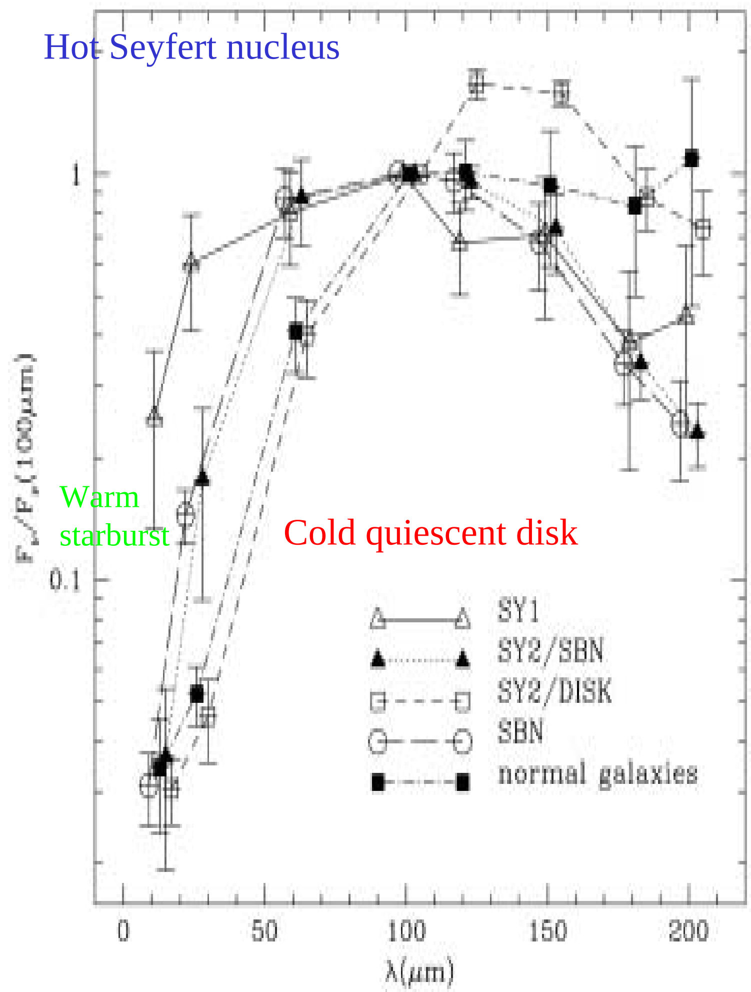
Empirical Luminosity Evolution predictions
from Malkan and Stecker 2001

SPIRE will have tremendous cosmological "reach": the very high surface densities of z>1 galaxies (at the confusion limit!) will show directly how the LF evolves for normal and active galaxies, independent of extinction



Three-filter photometry covering rest wavelengths of 40--150μm is adequate to make a rough ***classification of galaxy SEDs***, iff we have a rough idea of their redshifts: Seyfert 1's have much hotter dust (nuclei dominate at 12--20um), but Seyfert 2's can resemble (moderately warm) starbursts *or* normal disk galaxies.
The AGN gives NO CONTINUUM SIGNATURE longward of 60um.

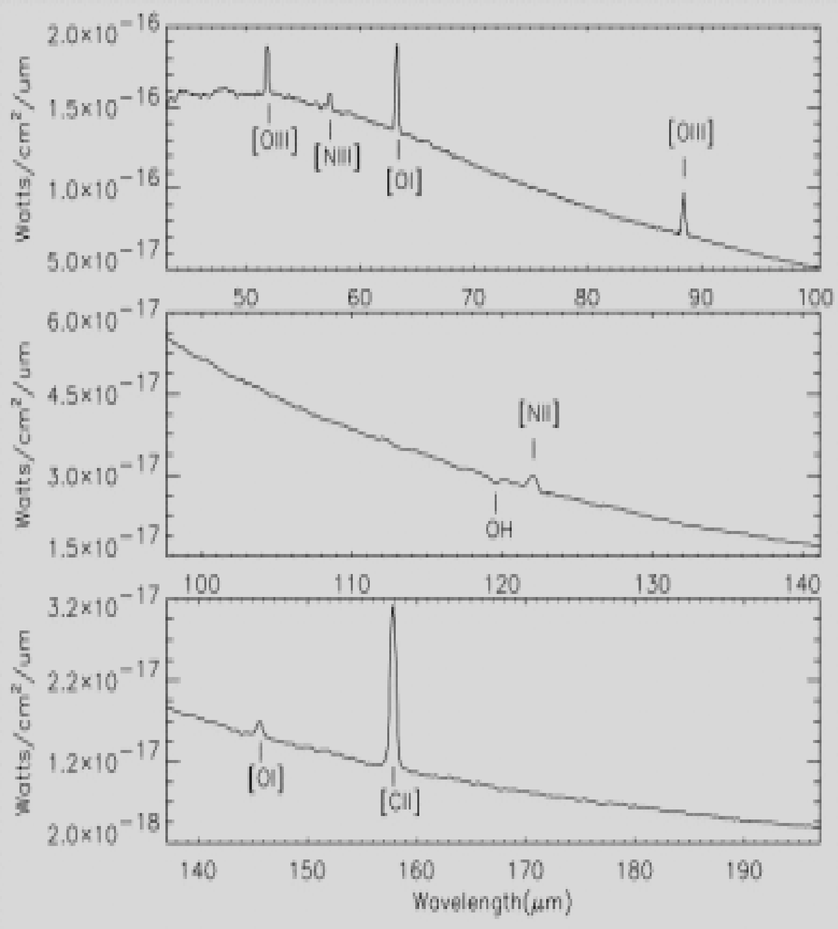
PACS+SPIRE will classify z>1 galaxies too distant and faint for MIPS



ISOPHOT photometry out to 200μm
(Spinoglio, Malkan, Andreani 2002)

INFRARED SPECTROSCOPY will provide more detailed information: ISO confirmed predictions of Spinoglio and Malkan (1992) for starbursts and Seyferts:

Starbursts have *strong*, well understood FIR
ionic emission lines
ex: M 82 ISO/LWS spectrum
R=150 $\rightarrow$
is very well fitted with a simple model:
Colbert et al 2000



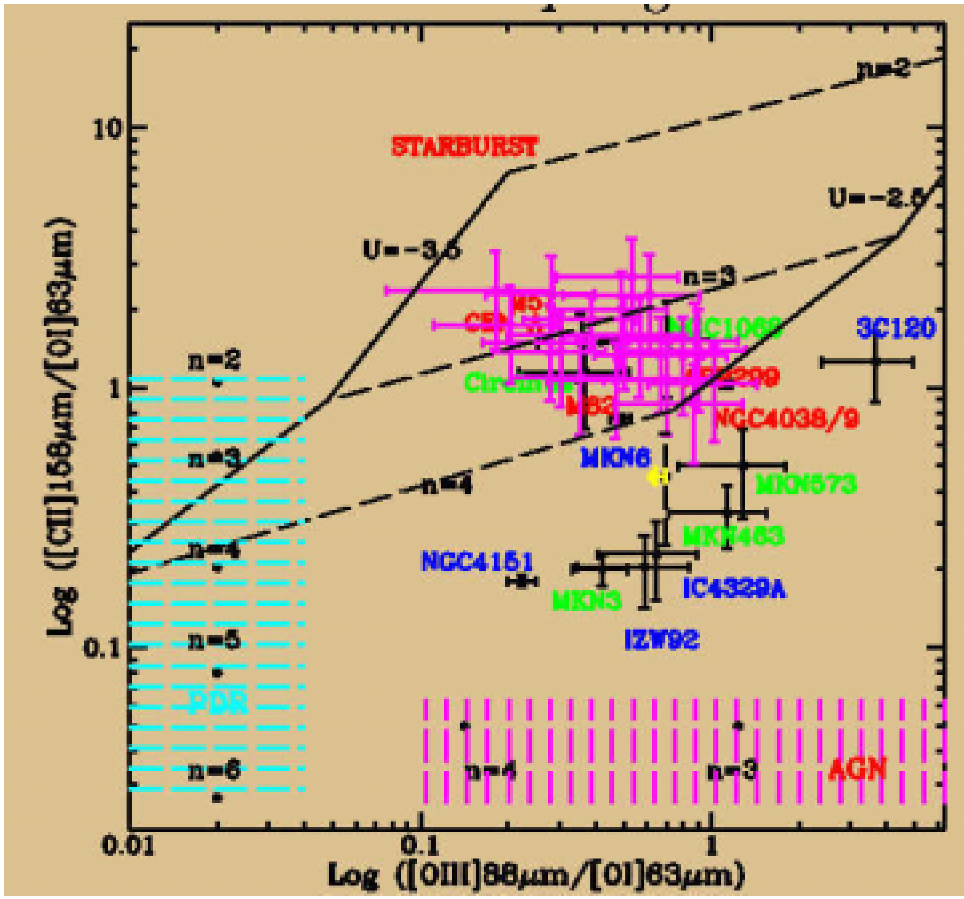
Line Ratio	Measured Ratio	Instantaneous[a]	Continuous[b]
[O III] 52 μm/[N III] 57μm	3.0 ± 0.4	3.0	3.1
[O III] 52 μm/[O III] 88 μm	1.24 ± 0.08	1.26	1.32
[O III] 52 μm/[O I] 63 μm	0.59 ± 0.04	0.59	0.59
[O III] 52 μm/[N II] 122 μm	6.3 ± 0.5	6.3	6.6
[O III] 52 μm/[O I] 145 μm	9.4 ± 0.9	9.2	10.5
[O III] 52 μm/[C II] 158 μm	0.82 ± 0.04	0.82[c]	0.82[c]
[N III] 57 μm/[N II] 122 μm......	2.1 ± 0.3	2.1	2.1
[O I] 63 μm/[O I] 145 μm	15.9 ± 1.4	15.5	17.9
[O I] 63 μm/[C II] 158 μm	1.38 ± 0.03	1.39	1.41
[N II] 122 μm/[N II]205 μm	4.1 ± 1.4[d]	4.4	4.9

Strong Emission Line Diagnostics:

Seyfert 1 (blue) and 2 (green) galaxies have ([OI]+[OIII]) / CII > 2.5, unlike all non-Seyferts (pink).

The difference between Seyferts and quiescent galaxies is an order of magnitude. Starbursts are intermediate, as are some composite objects like NGC 1068

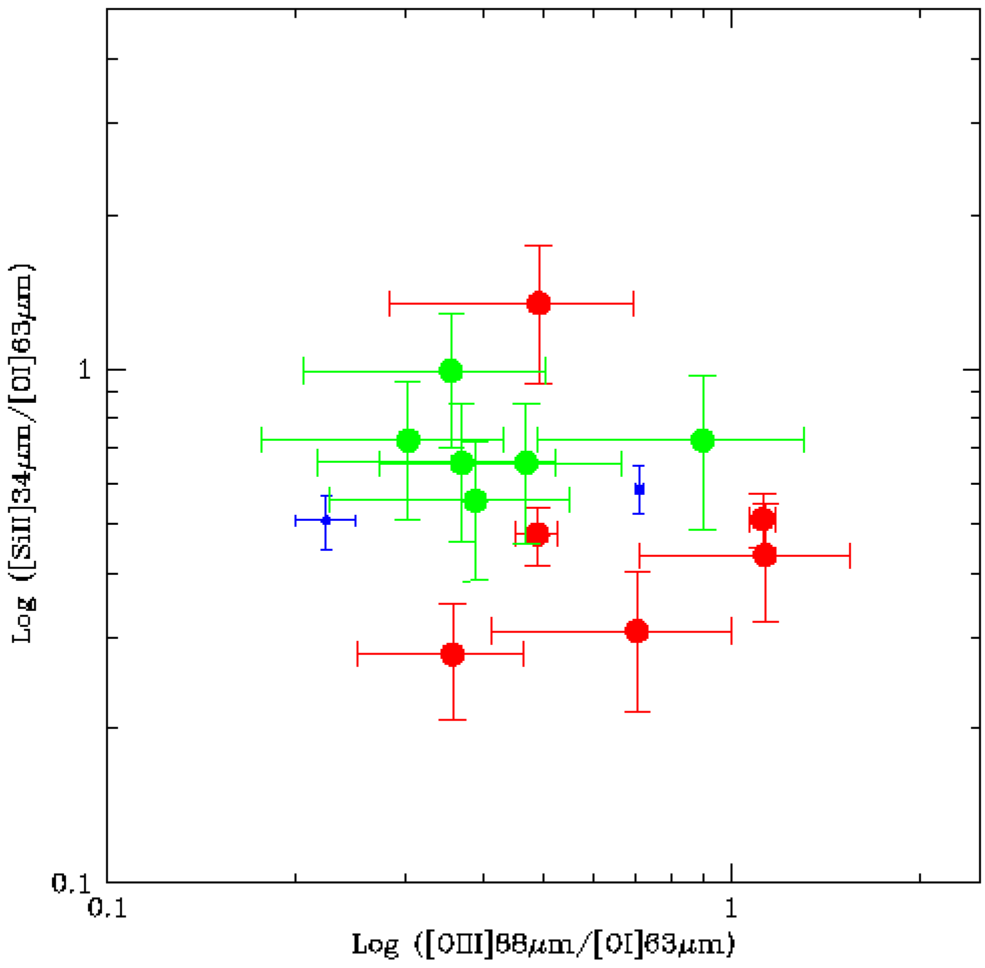
Models: quiescent galaxies are PDR-dominated, starbursts produce more O++, while Seyfert has O I from denser gas heated by X-rays [Malkan et al. 2004]



At higher redshifts, substitute Si II] 35µm for C II] 158µm, and [O III] 52µm for [O III] 88µm

green=normal;red=Sy1; blue=Sy2

At even higher redshifts, the 450µm channel of ALMA will do it all.



What about some very dusty ULIRGs with only weak forbidden lines? Don't worry: observe their ***<u>OH Absorption Lines</u>*** (especially 79 and 119μm, see M82 above)
These same transitions are seen in *emission* only in the archetypical Seyfert 2 galaxy, NGC 1068! ----->

Line id.λ	Flux ($10^{-19} W cm^{-2}$) Observed	Modeled	Notes
34μm	< .5	-0.5	(absorption)
48μm	...	0.12	
53μm	< 1.2	-0.4	(absorption)
65μm	< 1.2	0.2	
79μm	0.80	1.10	
84μm	< 1.2	0.5	
96μm	...	0.3	
98μm	< 1.2	0.4	
115μm	...	.004	
119μm	1.20	1.31	
163μm	0.74	0.60	

LWS Observations of NGC 1068 from Spinoglio et al. 2004